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Effect of Slope Gradient on Vegetation Attributes of Ades Forest in Western Hararghe Zone of Oromia, Ethiopia

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ABSTRACT

This study was conducted in the Ades forest of Western Hararghe Zone, Ethiopia, to analyze the woody vegetation structure, diversity, and regeneration across three slope gradients: lower slope class (LSC: <10%), middle slope class (MSC: 10-20%), and upper slope class (USC: 20-30%). A total of 60 main plots (20 m × 20 m) were randomly sampled, with sub-plots designated for shrub, climber, and herbaceous species. Results showed significant ($P < 0.05$) effects of slope classes on woody species richness, diversity, evenness, and density. The study identified 65 woody species across 50 families, including 35 trees (53.85%), 26 shrubs (40%), and 4 climbers (6.15%). The average woody species density was 975.8 ha^{-1}, highest in USC (1251.25 ha^{-1}), followed by MSC (928.75 ha^{-1}) and LSC (747.5 ha^{-1}). Dominant species included Juniperus procera, Podocarpus falcatus, and Cupressus lucitanica. Species frequency decreased with increasing diameter classes, and total basal area varied by slope: 8286.83 m^2 in LSC, 10908.51 m^2 in MSC, and 10026.22 m^2 in USC. Regeneration status was poor, with average density of 117.9 ha^{-1} for seedlings (8.6%), 282.9 ha^{-1} for saplings (20.5%), and 975.8 ha^{-1} for mature trees (70.9%). LSC had 106.3 ha^{-1} seedlings and 120 ha^{-1} saplings, while MSC had 358 ha^{-1} seedlings and 286 ha^{-1} saplings, and USC had 747.5 ha^{-1} seedlings and 928.8 ha^{-1} saplings. Herbaceous dry biomass yield and basal cover were also affected by slope gradient, with LSC showing higher yields (1.22 ton ha^{-1}) and cover (75.95%) as compared to MSC (1.09 ton ha^{-1} dry biomass yield and 66.55% basal cover) and USC (1.03 ton ha^{-1} dry biomass yield and 64.35% basal cover). Overall, increasing slope gradient positively influenced woody species diversity but negatively impacted herbaceous biomass yield and basal cover. Human and livestock interventions pose significant challenges to vegetation structure. Effective ecological, socio-economic, and policy measures are recommended for sustainable forest management.

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KEYWORDS: *Slope Gradient, Density, Species Richness, Herbaceous, Biomass Production and Basal Cover.*

INTRODUCTION

Forests are crucial in conserving biodiversity, reducing soil erosion, protecting watersheds, and sustaining indigenous ways of life (UNFCCC, 2015). Forests are a form of natural capital that supports economic growth and act as carbon sinks, helping mitigate greenhouse gas emissions. Topography influences climate by affecting sunlight distribution, air currents, and proximity to water bodies. Among the various aspects of topography, slope gradient is a key factor that impacts soil development (Plaster, 2013). More recent studies have shown that topography also affects species associations, as local water and nutrient availability in tropical forests around the world is influenced by these topographical features (Cannon & Leighton, 2004; Valencia *et al.,* 2004).

Vegetation cover in mountain areas is vital for local and regional climates and helps reduce erosion. The livelihoods of communities living in these regions are closely linked to forests and plant life. Moreover, vegetation provides essential protection against natural hazards such as rockfalls, landslides, debris flows, and floods (Brang *et al.,* 2001). The safety of settlements and transportation corridors in alpine regions largely depends on the protective functions of

vegetation (Agliardi and Crosta, 2003). Consequently, understanding the distribution and growth patterns of vegetation, along with the factors that influence them in these areas, is vital and has been the subject of research by various scholars (Endress and Chinea, 2001; Bai *et al.,* 2004).

Topography is the primary factor influencing vegetation growth, while soil type and rainfall amount play secondary roles, particularly on hill slopes (Dawes and Short, 1994). Slope is a key topographic element that affects the distribution and patterns of vegetation in mountainous areas (Titshall *et al.,* 2000). In recent years, the variation in species diversity along environmental gradients has become a major focus of ecological research. This variation has been explained through factors such as climate, productivity, biotic interactions, and habitat heterogeneity (Currie & Francis, 2004; Willig *et al.,* 2003; Shaheen *et al.,* 2012b). Vegetation patterns are influenced by environmental factors that display variability across space and time, including climate, topography, soil, and human disturbances (Alexander, 2000). Ecologists consider species diversity a crucial measure of a community's structural heterogeneity. A community can exhibit species diversity in several ways, including species richness, dominance by a few species, relative abundance (evenness), presence of rare and non-native species, vertical and horizontal stratification, and variety of growth forms.

Ethiopia's varied geography, climate, and soil support diverse vegetation, ranging from alpine ecosystems to desert plants, which offer important economic, socio-cultural, and environmental benefits. Environmental factors on the Earth's surface play a crucial role in influencing plant diversity and the distribution of vegetation (Muhammad *et al.,* 2012).

The variation in plant communities and species diversity is closely related to several ecological gradients (Kessler, 2001; Schmidt *et al.,* 2006). Understanding the relationship between community structure, species composition, and diversity in woodlands concerning elevation gradients and other environmental variables has become a critical issue in the fields of ecological and environmental sciences (Austrheim, 2002). Examining the relationship between mountain vegetation and its environment is a fundamental aspect of both vegetation and mountain ecology (Fang *et al.,* 2004).

Vegetation characteristics in a given site can be observed and measured through parameters like type, composition, diversity, density, dominance, and age structure of species. These attributes define the functional role and diversity of vegetation. However, various threats have led to the degradation of many tropical forests, impacting their structural integrity, species composition, and productivity. This degradation often results in conditions that differ from the expected natural forest types. It is estimated that approximately 350 million hectares of forests have been deforested, in addition to another 500 million hectares of both secondary and primary tropical forests that have experienced degradation (ITTO, 2002).

The rapid decline of tropical forests is partly due to a limited understanding of their structure and ecological functions. Studying plant communities is vital for effective conservation strategies, as these communities vary spatially and temporally. Analyzing environmental gradients helps us identify the causes behind their patterns and distributions. Therefore, assessing variations in environmental variables is essential for understanding the factors that influence species distribution (Getachew *et al.,* 2008). Furthermore, examining the patterns of population structures can provide important insights into their regeneration and recruitment status, which can be used to inform conservation efforts (Demel, 2005).

Numerous studies have been conducted in various regions of Ethiopia to assess the carbon stock in different forest types across varying slope gradients (Tibebu and Teshome, 2015; Adugna and Soromessa, 2017; Hamere *et al.,* 2015). However, these investigations did not consider species diversity indices or the herbaceous vegetation present along different slope gradients in the Ades Forest located in the East Hararghe Zone. Consequently, it is imperative to identify and investigate the impacts of slope gradient on woody vegetation composition, herbaceous biomass production, and herbaceous basal cover within these study areas.

Objective

- To analyze the composition, diversity, and structure of woody plant communities, as well as the dry biomass yield of herbaceous species along the slope gradient.

MATERIALS AND METHODS

Location of the Study Area

The study was conducted in Ades forest, located between 9°14′60.00″N and 41°00′0.00″E. The study location is situated 407 km east of Addis Ababa and 30 km from Hirna Town, within the western Hararghe Zone of the Oromia National Regional State in Ethiopia. The altitude of Ades forest ranges from 2,517 to 2,743 meters above sea level. The total forest coverage of the study area is estimated to be 483 hectares, and it is home to a diverse plant and animal species.

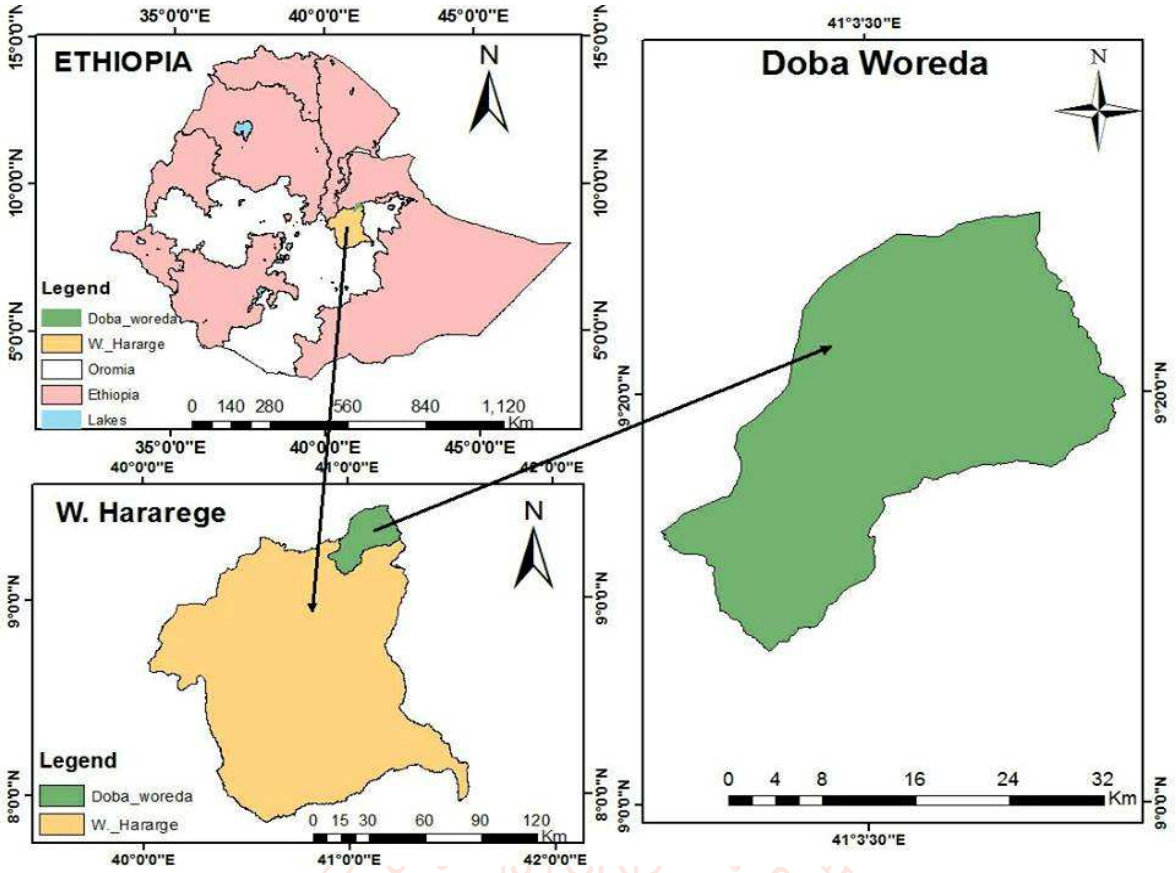

Figure 11: Map of the study area

Total Rainfall, Maximum and Minimum Temperature

The weather conditions in the study area were characterized by a cold climate, locally referred to as 'Dega.' The rainy season typically occurs between July and September, while the dry and hot season predominantly spans from mid-December to the end of March. The meteorological data from the Hirna meteorological station, located 30 kilometers from the study site, over 15 years (from 2002 to 2016) indicates that the mean annual rainfall fluctuates between 698 mm and 1,185 mm, as reported by the National Meteorological Agency of the Jigjiga branch (figure 2). Furthermore, according to the same agency, the mean annual maximum and minimum temperatures recorded in the Ades forest range from 27.9 degrees Celsius to 8.2 degrees Celsius (figure 2).

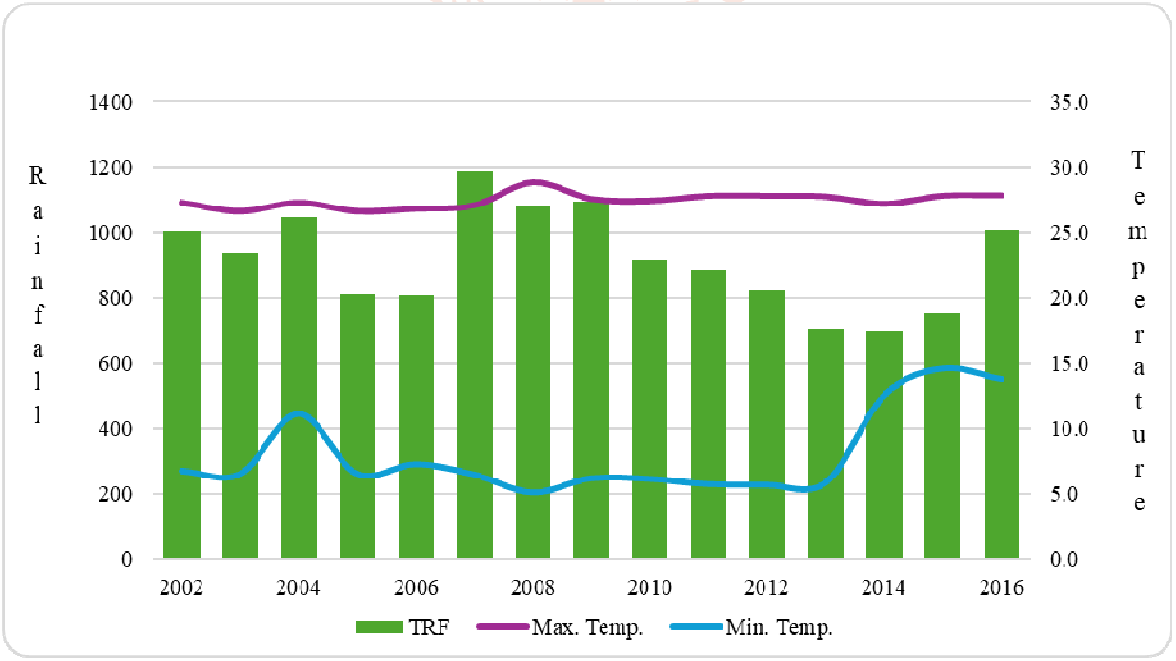

Figure 22: Annual precipitation, maximum and minimum temperature of Ades district. (TRF = Total Rainfall, Min.Temp. = Minimum Temperature, Max. Temp = Maximum Temperature)

Geology and Soil

The majority of the study area and its surroundings are enclosed by limestone and granite types of rock, and the soil type was mostly sandy and clay soil, with some loamy soil, which are important for having moderate soil organic carbon in the study area. Over cultivation, over grazing and some other human interference had highly affected the vegetation and fertility of the soil (Kidanemariam, 2014).

Vegetation and Fauna

The vegetation cover of Ades forest comprises forest, bush land, shrub land, communal land, and grazing land. Some plantations are stands of exotic species scattered with natural forest. The Ades forest contains different types of indigenous and exotic trees, which are largely dominated by *Juniperus procera, Podocarpus falcatus*, and *Cupressus lucitanica.* The majority of indigenous plants are large in height, wide in diameter, and very aged (Kidanemariam, 2014).

Ades forest was also the habitat of different types of wild animals such as a carnivores groups like *Panthera pardus, Hyaena hyaena, Canis mesomelas*; herbivores like antelope, *Tragelaphus scriptus, Lepus abysinicus, Hystrix* spp.; birds such as *Frankolinus clappertoni, Numida melagris* and other different kinds, arborial animals such as *Cercopithecus aethiops*, *Papio anubis* and *Colobus abysinicus* and some omnivores such as *Potomochoerus porcu* (Kidanemariam, 2014).

Data Collection and Measurement Methods

Plot Sampling Method

Experimental plots were drawn from Lower Slope (≤10 %), Middle Slope (>10 - ≤ 20%) and Upper Slope (>20 - ≤30%) classes purposively (Tibebu and Teshome, 2015). A space of 200m was left at the periphery/border of the study site to avoid edge effect; adjacent/similar plots were left to avoid pseudo replicated plots.

Slope Gradient Measurement Method

Slope gradient measurements were conducted using clinometers, a tripod, a rope, and a tape measure, depending on ground accessibility and vegetation cover. The slope was classified into three categories: Flat (<10%), Moderate (10% to <20%), and Steep (>20% to <30%). These measurements and classifications were carried out with the assistance of a researcher from the natural resource research department at Fedis Agricultural Research Center, who is an expert in forest and natural resources. The slope gradient classification at the experimental site was calculated using the formula: Vertical Interval (VI) divided by Horizontal Interval (HI), multiplied by 100.

$$\text{Slope} = \frac{\text{VI}}{\text{HI}} \text{x} 100 \Longleftrightarrow \text{Slope} = \frac{\text{Rise}}{\text{Run}} \text{x} 100$$

(**https://www.firstinarchitecture.co.uk/how-to-calculate-slopes-and-gradients/**)

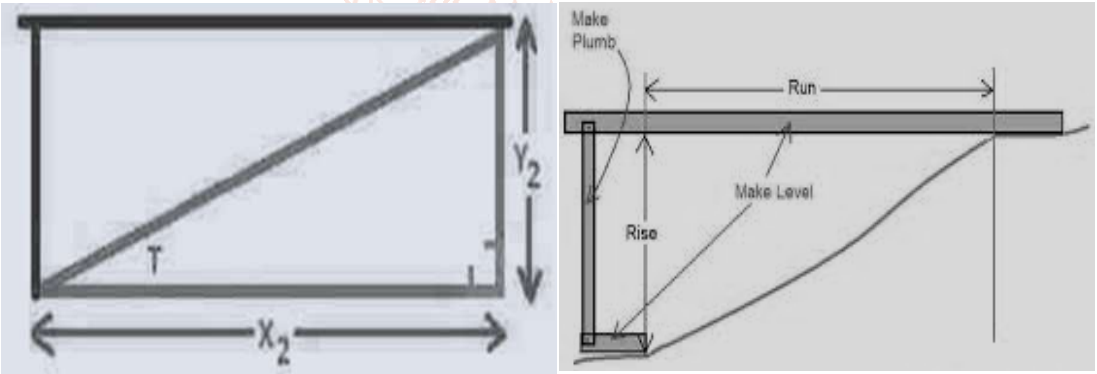

Figure 3: Slope determination (Y_2=Rise, X_2=Run, T= Angle degree)

Woody Plant Species Sampling

A quadrat of 20 m x 20 m (400 m^2) size was laid randomly within each slope gradient class (Bekele *et al.,* 2018). Accordingly, within the main quadrat a sub-quadrat of 5 m x 5 m was laid at the center for the sampling of shrubs and climbers. Twenty sample plot data were collected from each slope gradient class to study woody species diversity, woody species density, and woody species frequency. Measurement of Diameter at Breast Height (DBH) for trees; Diameter at Stump Height (DSH) for shrubs and climbers was used to estimate basal area cover estimation of woody plants. Diameter at breast height (1.3 m) of each woody species with a diameter of ≥ 2.5 cm was measured using tree calipers; woody species with DBH ≤ 2.5 were only counted for regeneration status determination (Gemedo, 2004). The number of individuals of each woody species was counted for each plot.

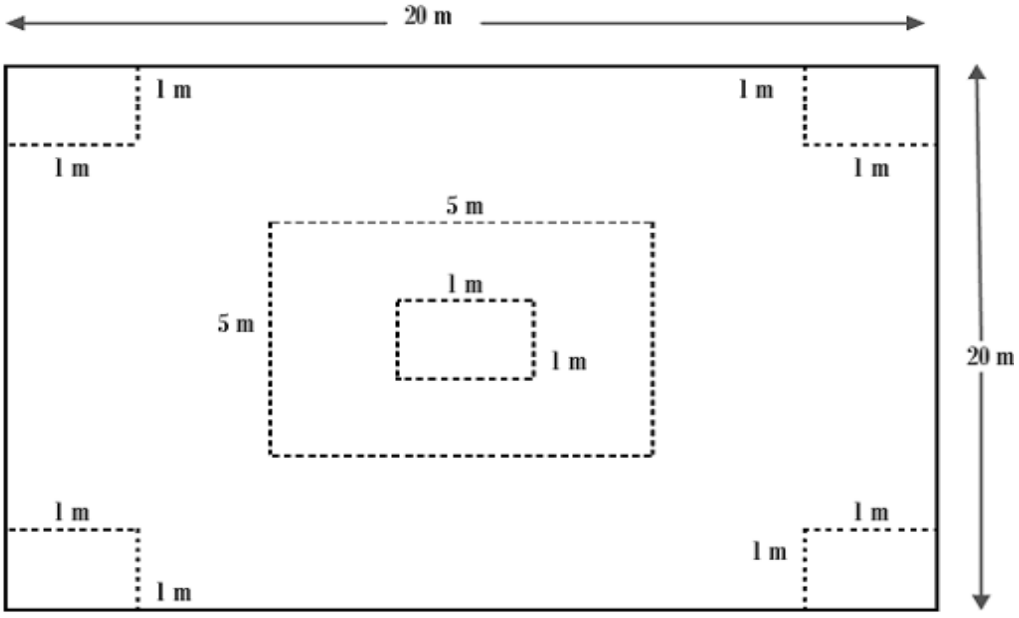

Figure 4: Quadrat and sub-quadrat arrangement

Trees and shrubs lying on the border of the quadrat; with more than 50% of their basal area falling within the quadrat were included within the quadrat; where more than 50% of their basal area falls outside the quadrat were excluded (Bhishma *et al*., 2011). Sapling and seedling population were counted from the centre within the main quadrat (5 m x 5 m sub-quadrat). Woody plants, which have multiple stems at 1.3 m height, are considered as a single individual and DBH of the largest stem was taken. Branched woody plants at 1.3 m were measured at the smallest point below 1.3 m, where the stem assumes near cylindrical shape. A woody plant with multiple stems or fork below 1.3 m height was counted as a single individual. Caliper and meter were used for DBH measurement of woody vegetation. Woody species were marked using color chalk to avoid double counting within the same quadrat. Primarily identification of woody plant species was done at the field using their local name with the help of elder peoples, experts and experienced personnel's. Each woody plant species identified at field level was cross checked for its botanical name using volumes of Flora of Ethiopia and Eritrea (Mark *et al*., 2002). Woody vegetation sampling plots (20 m x 20 m) were measured using two tape meters having a length of 50 m. Stems counted inside the quadrat were recorded in the data book. Then, raw data in the data book was copied to excel sheets for SAS software preparation.

Herbaceous Plant Dry Biomass and Basal Area Cover Sampling

Herbaceous plant dry biomass yield sampling and the basal cover were collected from a sub-quadrat of 1 m × 1 m (which was laid at four corners and the center of the main quadrat). Herbaceous plant dry biomass yield (ton ha^{-1}) and basal cover (%) parameter samples of 100 quadrats (5 x 20) were collected from each slope gradient class (i.e., resulting in a total of 300 samples). Destructive method of sample collection was used to estimate herbaceous biomass yield. Herbaceous vegetation was harvested at the ground level using hand shears (sickle) from each quadrat. Then, the fresh cut samples were weighed using a sensitive balance immediately after harvesting. About 50% of the fresh biomass was collected in paper bags and transported to Fadis Agricultural Research Center for dry matter yield analysis. Finally, the samples were oven dried at 105 ^{o}C for 24 hours and weighed to determine the dry matter yield of herbages (Whelly and Hardy, 2000). Herbaceous vegetation basal cover was determined with visual observation of ground covered with herbaceous vegetation percentage (%) within the quadrat (1m x 1m) or subtracting the percentage (%) of bare land cover of the quadrat.

Data Analysis

Herbaceous vegetation Basal Cover

The percentage of basal cover or bare ground for herbaceous plants was estimated with visual estimation of the percentage of herbaceous vegetation cover in each quadrat (Braun-Blanquet, 1932). Herbaceous basal cover was calculated by the equation:

$$HBC(\%) - 100 - BLC(\%)$$

Where:
HBC= Herbaceous Basal Cover
BLC= Bare Land Cover

By dividing the sub-quadrat into mini plots of 25 cm x 25 cm size; we can increase the accuracy of our visual estimation and help to increase the accuracy of basal cover estimation (Figure 5

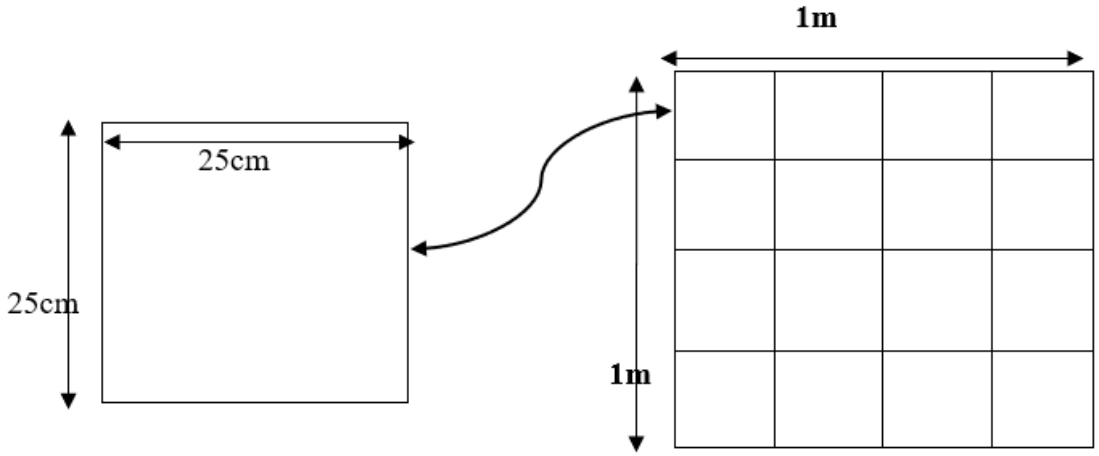

Figure 5: Systematic division of quadrat to estimate basal cover of herbaceous vegetation

Herbaceous Vegetation biomass yield analysis

A representative sample of 100gm fresh herbaceous biomass yield was obtained from each 1m x 1m quadrat by clipping (Tessema and Yvan, 2007). The collected biomass was oven dried at 105 ^{o}C for 24 hours (Whelly and Hardy, 2000). Then the dry sample weight was multiplied by 10,000m^2 to estimate dry matter yield production per hectare of the study area (ton DM ha^{-1}).

Woody Vegetation Analysis

The important quantitative analysis, such as density, frequency, and abundance of tree species, shrubs, and climber species, was determined by the Curtis and McIntosh (1950) method.

Density

Density is an expression of the numerical strength of a species where the total number of individuals of each species in all the quadrats is divided by the total number of quadrats studied.

Density was calculated by the equation:

$$\textbf{Density} = \frac{\text{Total number of individuals of a species in all quadrats}}{\text{Total number of quadrats studied}}$$

Frequency (%)

This term frequency refers to the degree of dispersion of individual species in an area and usually expressed in terms of percentage occurrence. It was studied by sampling the study area at several places at random and recording the name of the species that occurred in each sampling unit.

It is calculated by the equation:

$$\textbf{Frequency (\%)} = \frac{\text{Number of quadrats in which the species occurred}}{\text{Total number of quadrats studied}} \times 100$$

Relative Density (RD), Relative Frequency (RF), Relative Dominance (RDo) and Importance Value Index (IVI) are methodological measurements that are used to assess the ecological contribution of woody species to the plant community.

Relative Density

Relative Density is defined as the number of plants of a certain species per unit area. Relative density is calculated by counting the available individual plant community in the quadrat. Counting was undertaken visually; the sum of individuals per species was calculated in terms of species density per convenient area unit, such as a hectare (Mueller-Dombois and Ellenberg, 1974).

Relative density was calculated as the percentage of the density of each species divided by the total stem number of all species ha^{-1}.

$$\textbf{Relative density} = \frac{\text{Total No of individuals species A}}{\text{Total No of individuals of all species}} \times 100$$

Relative Frequency

Relative frequency of a species was computed as the ratio of the frequency of the species to the sum total of the frequency of all species in the study site.

$$\textbf{Relative frequency} = \frac{\text{Frequency of species A}}{\text{Frequency of all species}} \times 100$$

Relative Dominance

Relative dominance was calculated as the percentage of the total basal area of a species out of the total basal area of all species at the study site.

$$\textbf{Relative dominance} = \frac{\text{Dominance of species A}}{\text{Dominance of all species}} \times 100$$

Basal Area

Basal area is the area outline of a plant near the ground surface. It is the cross-sectional area of tree stems, diameter at breast height (DBH). Basal area of woody plants, the diameter at breast height was calculated for each tree stem.

$$BA - \pi r^2$$

Where:
Pi (π) = 3.1416
r = radius (in cm)

Importance Value Index of the Species

Important Value Index (IVI) was estimated by summation of woody species percentage values of relative frequency, relative density and relative dominance (Newton, 2007). IVI is useful to compare the ecological significance of species (Lamprecht, 1989). IVI=Relative density + Relative frequency + Relative dominance

Diversity indices

Diversity indices are utilized to assess the level of uncertainty in a habitat; higher diversity indicates a lower probability of encountering a particular species. These indices are straightforward mathematical expressions that condense extensive data into a single figure or set of figures. Among the various indices, the Shannon-Wiener diversity index (H') is the most widely applicable (Grieg-Smith, 1983). It was employed to evaluate species richness, species evenness, and overall species diversity within different plant community types. This index is favored for measuring species diversity because it incorporates both species richness and evenness, irrespective of sample size (Kent and Coker, 1992; Krebs, 1999). Typically, the value of the Shannon diversity index ranges from 1.5 to 3.5 and rarely exceeds 4.5 (Magurran, 1988).

Shannon diversity indices

Diversity is the most commonly used criterion for evaluating the conservation potential and ecological value of a site (Magurran, 1988). The Shannon diversity index is the most effective and widely utilized index, as it takes into account both species diversity and evenness within a community. This index assesses species composition and evenness in a given area or community. To determine species composition, diversity indices—including the Shannon diversity index, Simpson diversity index, and measures of evenness—were calculated as per the methodology outlined by Newton (2007).

It is computed by:-

$$H' = -\sum_{i=1}^{s} P_i \ln(P_i)$$

Where: H'= Shannon diversity indices
S= the number of species
Pi = proportion of individual species
LnPi=log proportion of individual species

Species evenness

Equitability or evenness used as a measure of similarity of the abundances of different woody species in the study site; it was analyzed by using Shannon's Evenness or Equitability Index (Magurran, 2004).

Equitability or evenness index was calculated using the following formula.

$$E = \frac{H'}{\ln(s)} = \frac{H'}{Hmax}$$

Where:
E = Evenness
H' = Shannon-Wiener Diversity Index
Hmax = lnS,
S = total number of species in the sample

Evenness (E') was calculated as Begon *et al.,* (2007), where the value of the evenness index falls between 0 and 1. The higher the value of evenness index, the more even the species is in their distribution within a given area. Evenness compares the similarity of the population size of each of the species present; it is a measure of the relative abundance of the different species making up the richness of an area. Complete evenness, only when the same number of individuals represents all the species, always equal to one. On the other hand, zero only; if there is only one species in the samples. A high value of evenness indicates that all the species in the community have rather similar abundance (Wilson *et al*., 1996).

Population structure

Population arrangement of each of the woody species in each slope gradient classes was assessed through histogram charts constructed by using the density of overall woody species. Then, based on the profile depicted in the population structures, the rejuvenation status of woody species was determined. In addition, the sapling, seedling and mature densities were compared based on their number as it can suggest to the rejuvenation potential of the area (Dhaulkhandi *et al*., 2008 ; Tiwari *et al*., 2010). All seedlings (height < 0.5m and DBH < 2.5cm), saplings with DBH < 5cm and height > 0.5m, and DBH > 5cm and height > 1.5m for mature woody individuals were counted and identified.

Statistical Analysis

The data obtained were subjected to one way ANOVA (Analysis of Variance) in the factorial experiment and analysis was carried out using the statistical analysis system with SAS version 9.1. All data that were generated from vegetation were used as dependent variables in one-way ANOVA analysis, while the slope gradient classes were used as the independent factor. Mean separations were considered at 5% least significant difference.

The statistical model used to analyze vegetation parameters was:

$$Y_{ij} = \mu + S_i + e_{ij}$$

Where: - Y_{ij} = over all observation
μ = the overall mean vegetation
S_i = slope gradient effect
e_{ij} = error effect

RESULTS AND DISCUSSIONS

Floristic Composition of Ades Forest

A total of 65 woody species from 49 families were recorded across 60 plots (see Appendix Table 1). Of the identified plant species, 35 (53.85%) were trees, 26 (40%) were shrubs, and 4 (6.15%) were climbers. In the lower slope class (LSC), tree species dominated the life form distribution at 77.9%, followed by shrubs at 19.2% and climbers at 2.8%. Similarly, in the middle slope class (MSC), trees comprised the largest proportion at 73.6%, with shrubs at 23.7% and climbers at 2.7%. The upper slope class (USC) also showed a predominance of tree species at 71.9%, followed by shrubs at 25.9% and climbers at 2.2%. Overall, the percentages of tree, shrub, and climber species were nearly consistent across all slope classes (Figure 6). This similarity suggests that variations in slope class have a minimal impact on the distribution of woody species percentages.

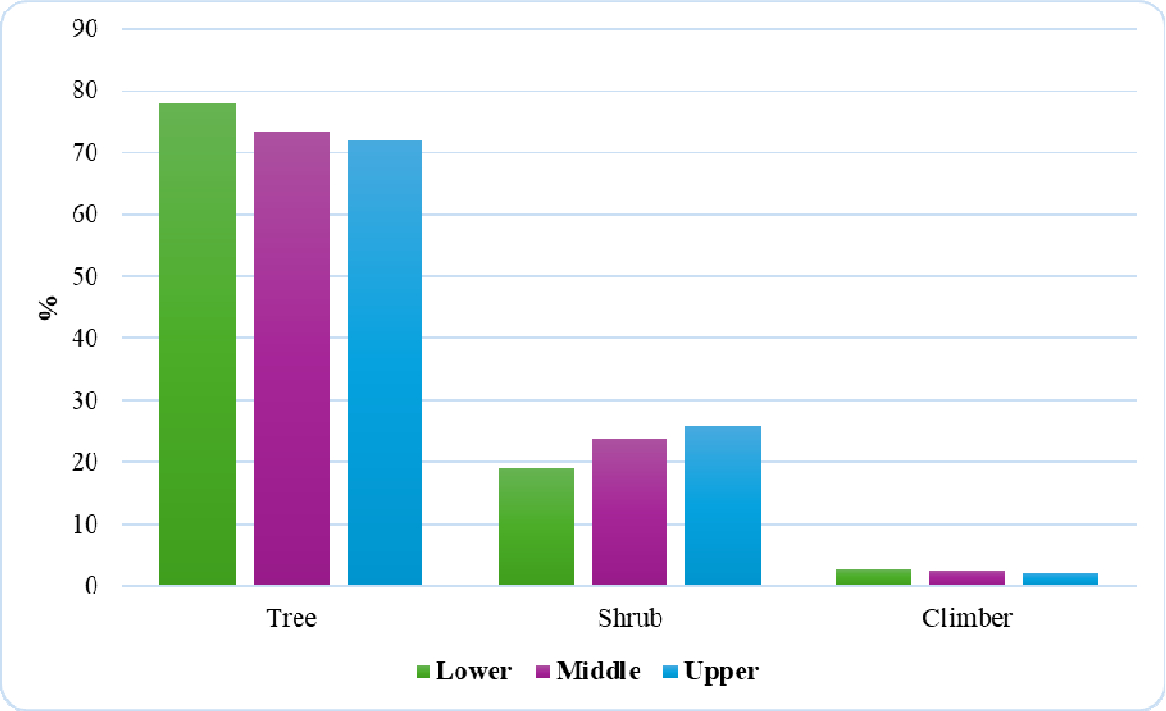

Figure 6: Woody flora species density of Ades forest. (Lower = LSC, Middle = MSC, Upper = USC)

This study indicates that the woody species composition of Ades Forest, with 65 species, is higher than that of Zengena Afromontane Forest, which recorded only 50 species (Tadele *et al.,* 2014). In comparison, the Kuandisha Afromontane Forest in Ethiopia documented 66 woody species (Berhanu *et al.,* 2016), which is nearly equivalent to that of Ades Forest. Conversely, a study of Tara Gedam and Abebaye forests reported a significantly higher number of woody species, totaling 143 (Zegeye *et al.,* 2011). The differences in floristic composition among various Afromontane study sites may be attributed to factors such as geographical location, soil characteristics, rainfall, and temperature. Additionally, variations in regeneration conditions and the overexploitation of certain woody species across different agro-ecological zones may also play a role. Furthermore, environmental heterogeneity, regeneration success, and competition are crucial factors influencing the species composition of forests in different research areas (Chen *et al.,* 2004).

Woody Species Families and Genera

Ades forest comprises a total of 65 species, 49 genera, and 59 families. Among these, trees account for 32 genera and 27 families, while shrubs consist of 23 genera and 18 families, and climbers include 4 genera and 4 families. Notably, the families *Euphorbiaceae* and *Myrtaceae* each have 3 genera, while *Cupressaceae, Oleaceae, Rosaceae,* and *Rubiaceae* contain 2 genera each. The remaining families, including *Araliaceae, Asteraceae, Boraginaceae, Combretaceae, Ebenaceae, Flacourtiaceae, Icacinaceae, Lamiaceae, Meliaceae, Melianthaceae, Moraceae, Myrsinaceae, Podocarpaceae, Proteaceae, Rhamnaceae, Rutaceae, Santalaceae, Sapindaceae, Scrophulariaceae, Sterculiaceae,* and *Ulmaceae*, each have just 1 genus.

In the shrub category, the study area features 23 genera and 18 families. The families *Fabaceae* and *Lamiaceae* each have 3 genera, while *Anacardiaceae, Celastraceae, Euphorbiaceae,* and *Rosaceae* have 2 genera each. Families such as *Acanthaceae, Asparagaceae, Asteraceae, Flacourtiaceae, Malvaceae, Myrsinaceae, Phytolaccaceae, Polygonaceae, Sapindaceae, Solanaceae, Simaroubaceae,* and *Verbenaceae* each contain 1 genus.

For climbers, there are 4 genera and 4 families, which include *Apocynaceae, Capparidaceae, Lamiaceae,* and *Myrsinaceae* as the only families found in the study area. Overall, Ades forest exhibits a greater number of tree families compared to shrub and climber families across all slope classes, indicating that trees are the dominant woody family in this ecosystem (Figure 7).

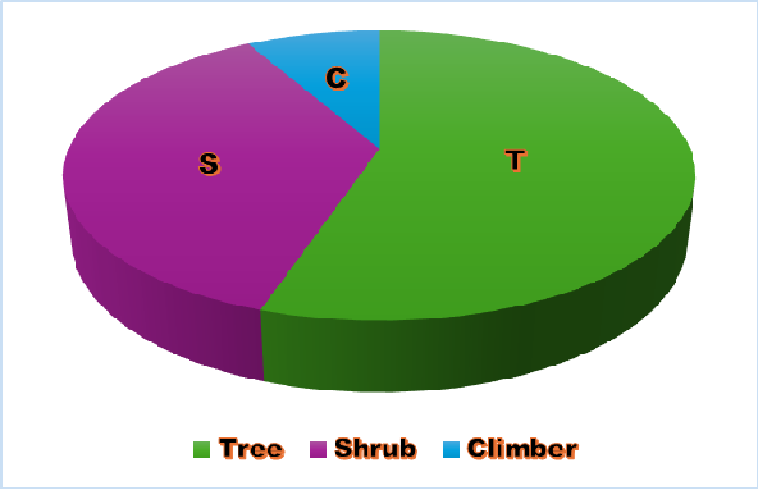

Figure 7: Tree, shrub and climber family percentage of Ades forest. (C= Climbers; S= Shrubs; T= Trees)

Woody Species Density

Woody species density significantly increases with the slope gradient. The highest density of woody plant species, measured at 1,251.25 ha^{-1}, was observed in the upper slope class (USC), followed by the middle slope class (MSC) at 928.75 ha^{-1} and the lower slope class (LSC) at 747.5 ha^{-1} (Figure 8).

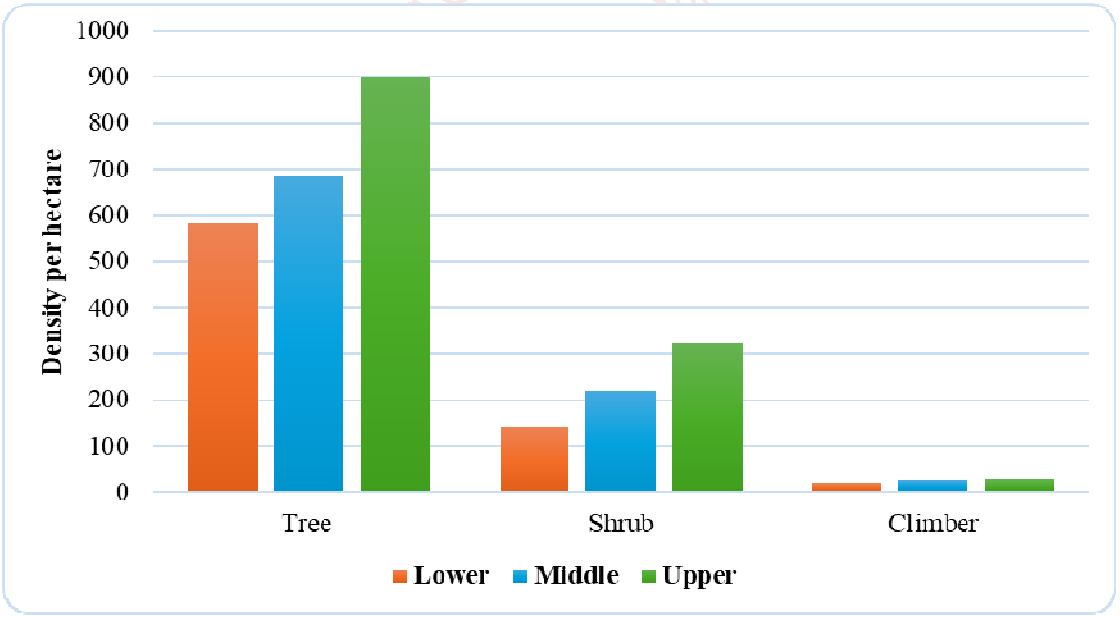

Figure 8: Woody species density along slope classes.

The lower slope class (LSC) exhibited the lowest density of tree species at 583 ha^{-1}, followed by the middle slope class (MSC) with a density of 684 ha^{-1}, and the upper slope class (USC) at 900 ha^{-1}. In contrast, shrub densities were significantly lower, recorded at 144 ha^{-1} in LSC, 220 ha^{-1} in MSC, and 32 ha^{-1} in USC. Climber densities were also low, with 21 ha^{-1} in LSC, 25 ha^{-1} in MSC, and 28 ha^{-1} in USC (Figure 8). Statistical analysis of the mean stem count per plot revealed that USC had a significantly ($P < 0.05$) higher woody species density compared to both MSC and LSC. While there was a statistical difference between MSC and LSC, it was not deemed significant. The variations in woody species density among the slope classes may be attributed to the suitability and accessibility of LSC and MSC to anthropogenic impacts, such as tree cutting and browsing, as well as inhibitory factors like the removal of seedlings during herbaceous biomass collection in peak production seasons. Additionally, competition for resources such as soil nutrients and moisture among mature trees, saplings, and seedlings likely plays a crucial role in shaping the species composition of the forest across different slope classes.

Density of Dominant Tree Species

The Ades forest features three dominant tree species. *Juniperus procera* is the most abundant, with densities of 217.5, 221.25, and 303.75 individuals ha^{-1} in the lower slope class (LSC), middle slope class (MSC), and upper

slope class (USC), respectively. The second most dominant species is *Podocarpus falcatus*, which has densities of 131.25 ha^{-1} in LSC, 110 ha^{-1} in MSC, and 166.25 ha^{-1} in USC. The third dominant species, *Cupressus lucitanica*, shows densities of 68.75 ha^{-1} in LSC, 118.75 ha^{-1} in MSC, and 82.5 ha^{-1} in USC. The density ranking of these species is as follows: *Juniperus procera* > *Podocarpus falcatus* > *Cupressus lucitanica* (Figure 9).

The agroecological conditions of the area likely support the dominance of these species. Factors such as climate, topography, and soil play crucial roles in shaping the species composition of the forest across different slope classes. Although woody vegetation may not be significantly influenced by soil factors as slope gradients increase, the survival, abundance, and dominance of these dominant species contribute to the prevalence of *Juniperus procera*, *Podocarpus falcatus*, and *Cupressus lucitanica* in the study area.

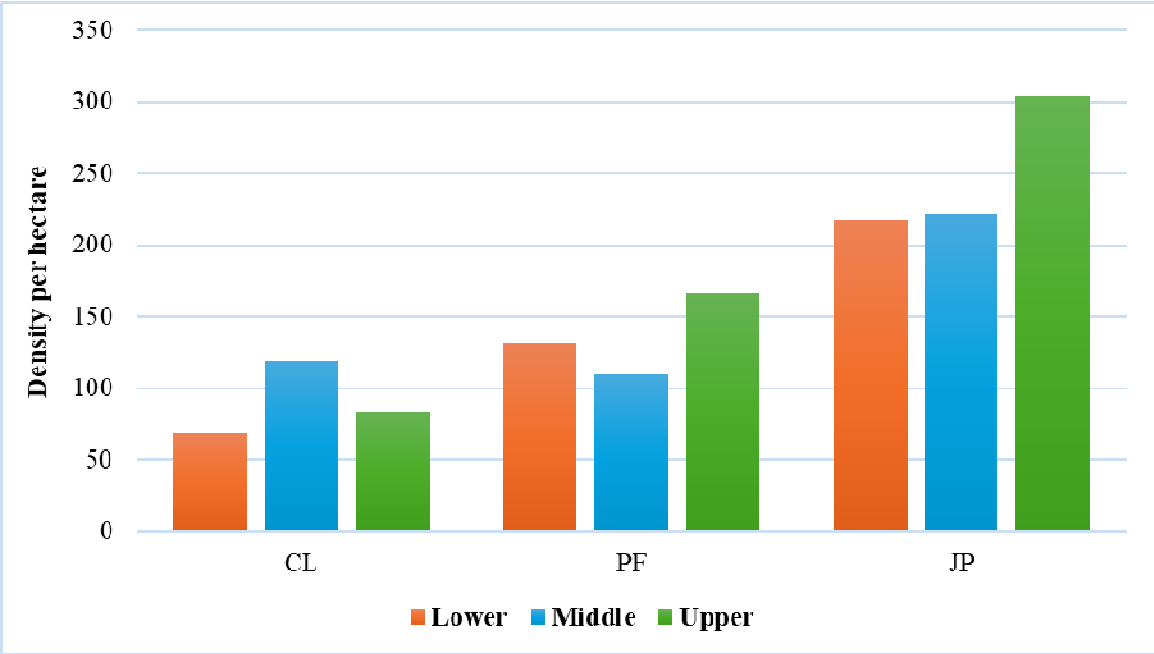

Figure 9: Density of major tree species of Ades forest along slope classes (CL = *Cupressus lucitanica*: PF = *Podocarpus falcatus*: JP = *Juniperus procera*)

Density of Major Shrub Species

In the lower slope class (LSC), *Ocimum spicatum* emerged as the dominant shrub species, with a density of 18.75 ha^{-1}. Following this, *Solanum incanum* and *Dovyalis abyssinica* had densities of 16.25 ha^{-1} and 11.25 ha^{-1}, respectively. In the middle slope class (MSC), *Maytenus spp.* was the dominant shrub, with a density of 27.5 ha^{-1}, while *Dovyalis abyssinica* and *Solanum incanum* had densities of 13.75 ha^{-1} and 12.5 ha^{-1}, respectively. Similarly, in the upper slope class (USC), *Maytenus spp.* again dominated, with a density of 35 ha^{-1}, followed by *Dovyalis abyssinica* and *Calpurnia aurea* at 27.5 ha^{-1} and 26.25 ha^{-1}, respectively. Moreover, *Rubus apetalus* and *Rosa abyssinica* had densities of 16.25, 7.5, and 6.25 ha^{-1}.

This study found that the highest density of major shrub species occurred in the MSC. This may be attributed to the favorable conditions for shrub growth in this part of the forest, which was characterized by abundant litter and organic matter.

Density of Major Climber Species

In the LSC *Carissa spinarum, Capparis cartilaginea, Becium filamentosum* and *Embelia schimperi* had a density of 8.75, 5, 3.75 and 3.75 individuals ha^{-1}. In the MSC *Becium filamentosum, Capparis cartilaginea, Carissa spinarum* and *Embelia schimperi* had a density of 7.5, 6.25, 6.25 and 5 individuals ha^{-1} respectively. In the USC, *Carissa spinarum, Becium filamentosum* and *Embelia schimperi* have a density of 12.5, 11.25 and 3.5 individuals per hectare respectively. Comparatively, the average density of major climber species was higher in USC, which might be due to lower disturbance and destruction compared to LSC and USC.

Diameter at Breast Height and Diameter at Stump Height of Woody Vegetation

The diameter at breast height (DBH) across the three slope classes was categorized into nine classes (Figure 10).

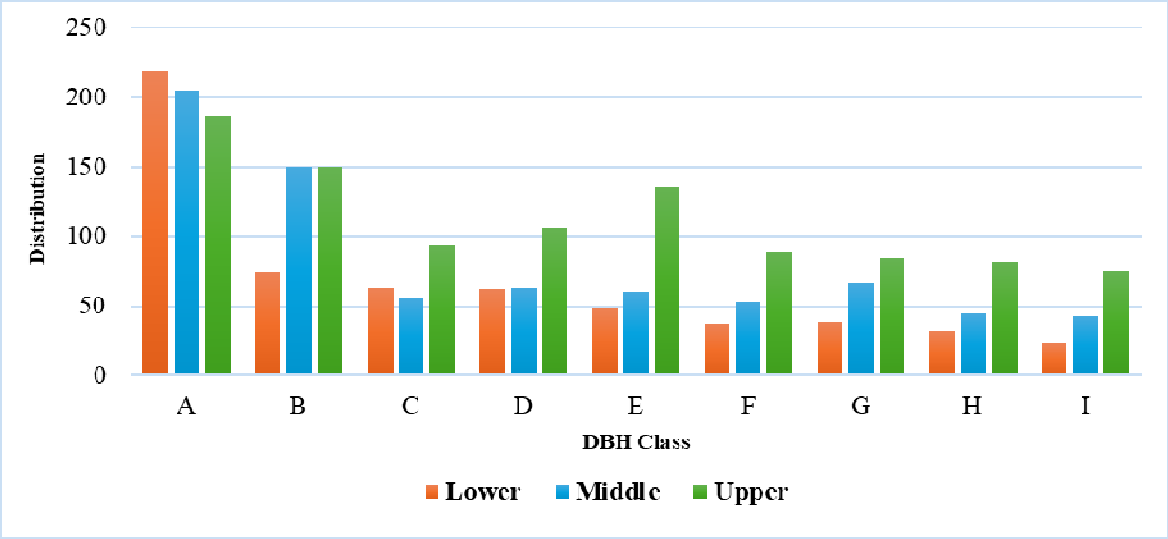

Figure 10: Diameter class distribution of woody species of Ades forest along slope class

DBH classes (A = ≥2.5cm and ≤5; B = 5.01-10cm; C = 10.01-15cm; D = 15.01-20cm; E = 20.01-25cm; F= 25.01-30cm; G = 30.01-35cm; H = 35.01-40cm; I > 40).

This study indicates that the Ades forest has a higher population and DBH class in the upper slope class (USC). The overall distribution of DBH classes reveals a general decline in woody species as we progress from lower to higher DBH classes, alongside a gradual increase in the number of large trees with increasing slope gradient. The decrease in stem count as we transition to higher DBH classes suggests a normal and healthy population structure (Tesfaye *et al.,* 2017; Ahmed *et al.,* 2017).This study reveals that woody species with lower DBH classes decrease as we move towards USC; because woody species having highest DBH exploitation was higher in LSC due to anthropogenic effects like deforestation.

Relative Density, Frequency, Basal Area and Important Value Index

Relative Density

Relative density indicates the number of plants of a specific species per unit area and was calculated by visually counting the individual plants in the quadrants (Mueller-Dombois and Ellenberg, 1974). In the Ades forest, *Juniperus procera*, *Podocarpus falcatus*, and *Cupressus lucitanica* are the dominant woody species in the lower slope class (LSC), with relative density of 29.1, 17.56, and 9.2, respectively (Table 1). Conversely, species such as *Apodytes dimidiata*, *Celtis africana*, *Cordia africana*, *Diospyros abyssinica*, *Oncoba spinosa*, and *Vangueria madagascariensis* have the lowest relative density at 0.17 each (Appendix Table 1).

In the middle slope class (MSC), *Juniperus procera*, *Cupressus lucitanica*, and *Podocarpus falcatus* again dominate, with relative densities of 23.82, 12.79, and 11.84, respectively (Table 1). The least abundant species in this class include *Apodytes dimidiata*, *Celtis africana*, *Clerodendrum myricoides*, *Cordia africana*, *Ekebergia capensis*, *Indigofera rothii*, *Myrsine africana*, and *Oncoba spinosa*, each with a relative density of 0.13 (Appendix Table 1).

In the upper slope class (USC), *Juniperus procera*, *Podocarpus falcatus*, and *Cupressus lucitanica* continue to be the dominant species, with relative densities of 24.28, 13.29, and 6.59, respectively. The least abundant species in this class include *Apodytes dimidiata*, *Asparagus africanus*, *Celtis africana*, Myrsine *africana*, and *Oncoba spinosa*, all with a relative density of 0.2. Notably, the relative density of *Juniperus procera* was highest in the LSC, followed by the USC and MSC, indicating its greater prevalence in the LSC.

Overall, the results highlight that the three dominant tree species *Juniperus procera*, *Podocarpus falcatus*, and *Cupressus lucitanica* are the most abundant woody species across all slope classes in the Ades forest. The abundance and dominance of these species contribute to the higher average relative density of dominant woody species in the study area, leading to the conclusion that *Juniperus procera*, *Podocarpus falcatus*, and *Cupressus lucitanica* are the densest and most abundant tree species in the study area.

Relative Frequency

In the lower slope class (LSC) *Juniperus procera*, *Podocarpus falcatus*, and *Ocimum spicatum* have relative frequency of 9.83, 8.67, and 5.2, respectively (Table 1). In contrast, species such as *Abutilon anglosomaliae*, *Apodytes dimidiata*, *Asparagus africanus*, *Brucea antidysenterica*, *Celtis africana*, *Cordia africana*, *Cussonia*

holstii, Diospyros *abyssinica*, *Dodonaea viscosa*, *Euphorbia ampliphylla*, *Ficus sur*, *Maytenus undata*, *Myrsine africana*, *Oncoba spinosa*, *Prunus africana*, *Rhamnus staddo*, *Rhus natalensis*, *Rumex nervosus*, *Syzygium guineense*, and *Vangueria madagascariensis* exhibit the lowest relative frequency of 0.58 each (Appendix Table 1).

In the middle slope class (MSC), *Juniperus procera*, *Podocarpus falcatus*, and *Cupressus lucitanica* show relative frequencies of 7.5, 7.5, and 5.5, respectively (Table 1). The least frequent species in this class include *Apodytes dimidiata*, *Celtis africana*, *Clerodendrum myricoides*, *Cordia africana*, *Cussonia holstii*, *Dombeya torrida*, *Ekebergia capensis*, *Ficus sur*, *Galiniera saxifraga*, *Indigofera rothii*, Myrsine *africana*, *Olea capensis*, *Oncoba spinosa*, *Rubus apetalus*, and *Rumex nervosus*, each with a relative frequency of 0.5 (Appendix Table 1).

In the upper slope class (USC), *Juniperus procera*, *Podocarpus falcatus*, and *Olea europaea* have relative frequencies of 7.8, 7.8, and 5.5, respectively (Table 1). The least frequent species are *Apodytes dimidiata*, *Asparagus africanus*, *Clerodendrum myricoides*, *Cussonia holstii*, *Grevillea robusta*, *Myrsine africana*, *Oncoba spinosa*, *Prunus africana*, *Psydrax schimperiana*, *Rumex nervosus*, and *Solanum incanum*, each with a relative frequency of 0.46 (Appendix Table 1). Frequency measures how widely individual species are spread within an area, reflecting how often a particular woody species appears in a specific habitat or ecosystem. Similar to the results from relative density, the relative frequency data shows that *Juniperus procera*, *Podocarpus falcatus*, and *Cupressus lucitanica* are the most commonly seen species across all slope classes. Together, the findings for both relative density and relative frequency shed light on the abundance and distribution of these tree species in the study plots, helping us estimate their respective density and frequency percentages in the area under investigation.

Relative Dominance

Hagenia abyssinica, Becium grandiflorum, and Podocarpus falcatus exhibit relative dominance values of 9.34, 7.86, and 7.74, respectively, within the LSC. In contrast, *Rumex nervosus* recorded the lowest relative dominance value of 0.15. In the MSC, the relative frequency values for *Hagenia abyssinica, Podocarpus falcatus,* and *Becium grandiflorum* are measured a value of 7.79, 7.22, and 7.05, respectively, while *Rumex nervosus* again showed the lowest relative dominance value of 0.13. Furthermore, in the USC, *Hagenia abyssinica, Podocarpus falcatus,* and *Becium grandiflorum* have relative dominance values of 8.47, 7.86, and 7.67, respectively, with *Rumex nervosus* recording a relative dominance value of 0.14 (see Appendix Table 1).

The metric of relative dominance reflects the prevalence of a given species and is calculated as the percentage of the total basal area of that species to the total basal area of all species at the study area. This investigation has determined that *Hagenia abyssinica* possesses the highest relative dominance percentage, while *Rumex nervosus* exhibits the lowest. Moreover, *Podocarpus falcatus* and *Becium grandiflorum* rank second in relative dominance when compared to other woody species within the study area.

Basal Area

According to the findings of this study, the total basal area of MSC is significantly greater than that of LSC and USC. Specifically, LSC exhibits a total basal area of 8286.83, whereas MSC and USC possess values of 10908.51 and 10026.22, respectively (refer to Appendix table 1). In the lower slope class, the dominant woody species include *Hagenia abyssinica*, *Becium grandiflorum*, and *Podocarpus falcatus*, which have total basal areas of 773.98, 651.56, and 641.2, respectively. Conversely, *Rumex nervosus* has the lowest total basal area within the LSC, measuring merely 12.75.

In the middle slope class, *Hagenia abyssinica, Podocarpus falcatus,* and *Becium grandiflorum* continue to dominate, with total basal area values of 849.69, 787.84, and 769.06, respectively. Once again, *Rumex nervosus* records the lowest total basal area at 14.05. The same pattern is observed in the upper slope class, where *Hagenia abyssinica, Podocarpus falcatus,* and *Becium grandiflorum* maintain their dominance with total basal area values of 849.69, 787.84, and 769.06. Notably, *Rumex nervosus* continues to exhibit the lowest total basal area value, recorded at 14.05.

Total basal area is recognized as a more effective measure of a species' significance compared to a simple stem count (Aliyi *et al.,* 2015). Thus, species contributing most significantly to the overall basal area within a given ecosystem or habitat should be regarded as the most important within that environment. If density alone is considered as a measure of dominance, shrubs may appear to be the primary species. Consequently, the aforementioned woody species are acknowledged as key contributors to above-ground woody biomass and possess substantial ecological significance within the study area.

Important Value Index

Importance Value Index (IVI) combines data from three parameters, which include relative frequency, relative density and relative dominance (Kent and Coker, 1992). The IVI value is an important parameter indicating the ecological significance of a species in a given ecosystem (Worku *et al*., 2012). Species with high IVI values are considered more important than those with low IVI values (Haileab *et al*., 2011). IVI values are also important in conservation programs where species with low IVI values are prioritized for conservation and those with high IVIs need monitoring management (Fekadu *et al*., 2012). Furthermore, IVI is a good measure for summarizing vegetation characteristics of a given habitat (Bekele *et al*., 2014; Tilahun *et al*., 2015). The IVI value of each slope class for some important woody species is indicated in decreasing order as indicated below(the overall IVI value was set in the Appendix Table 1).

Table 1: Woody species Important Value Index of lower slope class

Species Scientific name	RF	D	RD	BA	RDO	IVI
Juniperus procera	8.67	217.50	29.10	279.52	3.37	41.14
Podocarpus falcatus	9.83	131.25	17.56	641.20	7.74	35.12
Cupressus lusitanica	4.05	68.75	9.20	529.44	6.39	19.63
Olea europaea	2.89	35.00	4.68	590.21	7.12	14.69
Becium grandiflorum	2.31	7.50	1.00	651.56	7.86	11.18
Hagenia abyssinica	1.16	5.00	0.67	773.98	9.34	11.16
Ocimum spicatum	5.20	18.75	2.51	13.32	0.16	7.87
Cussonia holstii	0.58	2.50	0.33	517.68	6.25	7.16
Solanum incanum	4.05	16.25	2.17	14.45	0.17	6.39
Croton macrostachyus	2.31	11.25	1.51	168.02	2.03	5.84
Eucalyptus globules	1.73	22.50	3.01	87.21	1.05	5.80
Ficus sur	0.58	3.75	0.50	387.93	4.68	5.76
Prunus Africana	0.58	5.00	0.67	372.04	4.49	5.74
Eucalyptus camaldulensis	3.47	7.50	1.00	61.48	0.74	5.21
Sum of other species	**52.60**	**195.00**	**26.09**	**3198.81**	**38.60**	**117.29**
Total	**100**	**747.50**	**100**	**8286.83**	**100**	**300**

In the lower slope class (LSC), the tree species with the highest Important Value Index (IVI) were *Juniperus procera, Podocarpus falcatus,* and *Cupressus lucitanica*, exhibiting IVI values of 41.14, 35.12, and 19.63, respectively (Table 1). Conversely, *Vangueria madagascariensis* recorded the lowest IVI value, at 0.92 (Appendix Table 1). The findings of this study indicate that *Juniperus procera, Podocarpus falcatus,* and *Cupressus lucitanica* are the dominant tree species within the LSC, surpassing other woody species in terms of IVI. The study area is home to a total of 65 woody species, but it is primarily dominated by certain tree species. Notably, *Juniperus procera, Podocarpus falcatus,* and *Cupressus lucitanica* hold significant ecological importance, shaping the landscape and character of the vegetation. In summary, these tree species serve as indicators of the vegetation characteristics identified by Bekele *et al.* (2014) within the LSC. It is recommended that *Vangueria madagascariensis* be prioritized for conservation, along with enhanced monitoring and management practices, due to its low IVI value as noted by Fekadu *et al.* (2012).

Table 2: Woody species Important Value Index of middle slope class

Species Scientific name	RF	D	RD	BA	RDO	IVI
Juniperus procera	7.5	221.25	23.82	257.74	2.36	55.14
Podocarpus falcatus	7.5	110.00	11.84	787.84	7.22	31.19
Cupressus lusitanica	5.5	118.75	12.79	556.69	5.10	31.07
Olea europaea	4	48.75	5.25	627.81	5.76	14.50
Maytenus spp.	2.5	27.50	2.96	129.62	1.19	8.42
Grevillea robusta	2	16.25	1.75	41.60	0.38	5.50
Dovyalis abyssinica	2.5	13.75	1.48	48.00	0.44	5.46
Eucalyptus globulus	1.5	17.50	1.88	122.66	1.12	5.27
Argomuellera microphylla	2.5	11.25	1.21	21.80	0.20	4.92
Bersama abyssinica	1.5	13.75	1.48	119.92	1.10	4.46
Abutilon anglosomaliae	2	11.25	1.21	29.40	0.27	4.42
Calpurnia aurea	2	11.25	1.21	68.92	0.63	4.42

Croton macrostachyus	2	11.25	1.21	174.04	1.60	4.42
Rosa abyssincia	2	11.25	1.21	27.23	0.25	4.42
Solanum incanum	1.5	12.50	1.35	15.76	0.14	4.19
Becium grandiflorum	2	10.00	1.08	769.06	7.05	4.15
Becium filamentosum	2.5	7.50	0.81	17.49	0.16	4.12
Sum of other species	**49**	**255.00**	**27.46**	**7092.92**	**65.02**	**103.91**
Total	**100**	**928.75**	**100**	**10908.51**	**100**	**300**

In the middle slope class (MSC), *Juniperus procera, Podocarpus falcatus,* and *Cupressus lucitanica* have Importance Value Index (IVI) scores of 55.14, 31.19, and 31.07, respectively, as shown in Table 2. On the other hand, species such as *Apodytes dimidiata, Celtis africana, Clerodendrum myricoides, Cordia africana, Ekebergia capensis, Ficus sur, Indigofera rothii, Myrsine africana,* and *Oncoba spinosa* hold the lowest IVI value at 0.77 (Appendix Table 1.) Within the MSC, the dominant tree species are Juniperus procera, *Podocarpus falcatus,* and *Cupressus lucitanica*, which exhibit notably higher IVI scores compared to other woody species. This trend is also mirrored in the lower slope class (LSC), where tree species consistently rank the highest in IVI values among the woody vegetation surveyed in the area, surpassing the shrub and climber species. This highlights the ecological importance of *Juniperus procera, Podocarpus falcatus,* and *Cupressus lucitanica* in the the study area. In essence, these tree species act as key indicators of the vegetation characteristics found in the MSC habitat, which reflect similar patterns observed in the LSC. Conversely, species like *Apodytes dimidiata, Celtis africana, Clerodendrum myricoides, Cordia africana, Ekebergia capensis, Ficus sur, Indigofera rothii, Myrsine africana,* and *Oncoba spinosa,* with their low IVI scores, should be prioritized in conservation efforts (Fekadu *et al.,* 2012) within the MSC.

Table 3: Woody species Important Value Index of upper slope class

Species Scientific name	RF	D	RD	BA	RDO	IVI
Juniperus procera	7.80	303.75	24.28	257.74	2.57	56.35
Podocarpus falcatus	7.80	166.25	13.29	787.84	7.86	34.37
Olea europaea	5.50	68.75	5.49	627.81	6.26	16.49
Cupressus lusitanica	2.75	82.50	6.59	556.69	5.55	15.94
Croton macrostachyus	3.21	33.75	2.70	174.04	1.74	8.61
Maytenus spp.	1.83	35.00	2.80	129.62	1.29	7.43
Becium grandiflorum	4.13	20.00	1.60	769.06	7.67	7.33
Dovyalis abyssinica	2.75	27.50	2.20	48.00	0.48	7.15
Calpurnia aurea	2.75	26.25	2.10	68.92	0.69	6.95
Lippia adoensis	2.75	22.50	1.80	22.22	0.22	6.35
Justicia schimperiana	2.29	20.00	1.60	42.75	0.43	5.49
Rhus vulgaris	1.83	20.00	1.60	83.28	0.83	5.03
Eucalyptus globulus	1.38	22.50	1.80	122.66	1.22	4.97
V. madagascariensis	1.83	18.75	1.50	23.15	0.23	4.83
Combretum molle	2.75	12.50	1.00	27.14	0.27	4.75
Sum of other species	**48.73**	**371.25**	**29.67**	**6285.29**	**62.69**	**108.07**
Total	**100**	**1251.25**	**100**	**10026.22**	**100**	**300**

In the USC, *Juniperus procera, Podocarpus falcatus,* and *Olea europaea* emerged as the tree species with the highest Importance Value Index (IVI) of 56.35, 34.37, and 16.49, respectively (see Table 3). In contrast, *Myrsine africana* and *Oncoba spinosa* had the lowest IVI, recorded at just 0.86 (refer to Appendix Table 1). Likewise, within the USC, *Juniperus procera, Podocarpus falcatus, and Cupressus lucitanica* were dominant tree species, showing significantly higher IVI values compared to other woody species. The study found that the highest IVI value came from tree species, overshadowing shrubs and climbers in the area, which highlights the ecological importance of *Juniperus procera, Podocarpus falcatus,* and *Cupressus lucitanica* within the protected vegetation of Ades forest. Furthermore, this study suggests that these species are key indicators of the vegetation characteristics in the USC habitat, similar to those found in the LSC and MSC regions. However, given their notably low IVI values, *Myrsine africana* and *Oncoba spinosa* warrant priority attention for conservation efforts, as indicated by Tilahun *et al.*, (2015).

Woody Species Richness and Diversity

Species Richness

The ANOVA analysis results for woody species revealed that the mean species richness values for the Middle Slope Class (MSC) and Upper Slope Class (USC) are not significantly different. In contrast, the Lower Slope Class (LSC) demonstrated a significant difference ($P < 0.05$) when compared to both MSC and USC (refer to Table 4). Specifically, USC (10.9) and MSC (10.0) show higher mean species richness than LSC (8.65). In the study area, as the slope gradient increases, the average number of species tends to rise, largely due to reduced destruction and disturbance in MSC and USC compared to LSC. This trend has a positive effect on species richness. As highlighted by Zhang (2005), an increase in species numbers significantly enhances overall species richness, emphasizing the important role that species diversity plays in shaping the community's overall biodiversity.

Species Diversity

The analysis of the Shannon-Weiner diversity index for woody species across the three slope categories indicated a significant difference ($P < 0.05$) in the LSC, MSC, and USC. The results showed that USC and MSC had the highest mean diversity index values, with the value of 2.14 in USC, and 2.0 in MSC, while LSC had a lower mean value of 1.8. Notably, there was no significant difference observed between the diversity indices of USC and MSC. The elevated species diversity index in MSC can be attributed to the higher availability of litter and decomposition, which boosts the organic matter in the environment, thereby supporting a greater number of woody species. This wealth of species in the MSC leads to increased diversity. Furthermore, the comparatively lower levels of destruction and disturbance in MSC and LSC can be linked to the influence of the slope factor. According to Krebs (1994) and Magurran (2004), a Shannon-Weiner diversity index is classified as high when it exceeds 3.0, medium when between 2.0 and 3.0, low when between 1.0 and 2.0, and very low when under 1.0. Thus, while the Shannon-Weiner diversity indices for MSC and USC fell in the highest diversity index category, LSC was categorized as low. Remarkably, the Shannon diversity index observed in this study was lower compared to findings from other studies; for instance, a study in the Ylat forest of Meket Woreda in northeastern Ethiopia (Sisay, 2016) reported higher diversity. Similarly, research conducted at Gra-Kahssu Natural Vegetation in Southern Tigray showed a diversity index greater than that of this study (Tesfaye, 2017).

Species Evenness

The lowest evenness value observed in the LSC can be attributed to the rise of dominant woody species in both the MSC and USC. Species diversity is closely linked to species richness and evenness, making these three factors useful indicators of the restoration stage (Zhang *et al.,* 2006a). A statistical analysis of the average evenness across the plots reveals that LSC significantly ($P < 0.05$) differed from both MSC and USC (Table 4). Compared to the other slope classes, LSC is more vulnerable to human-induced destruction and disturbances, along with having lower litter cover and rates of decomposition. The mean evenness in LSC was 0.84, which is notably lower than the values recorded for USC and MSC, which were 0.9 and 0.87, respectively.

Table 4: Woody Species richness, diversity index, species evenness and density

Slope classes	Species richness	Species diversity (*H'*)	Species evenness (*J*)	Density (Ind. ha^{-1})
Lower (LSC)	8.65^{b}	1.8^{b}	0.84^{b}	90.32^{b}
Middle (MSC)	10.0^{a}	2.0^{a}	0.87^{a}	94.14^{b}
Upper (USC)	10.9^{a}	2.14^{a}	0.9^{a}	116.31^{a}
***P* -value**	0.0016	0.0001	0.0018	0.0004

Where: ^{a,b,c} Means within a column with different superscripts differ significantly ($P < 0.05$).

The decline in species evenness may be attributed to the rise of dominant species within an ecosystem. One potential explanation for the variations in species richness, diversity, evenness, and density could be the differences in slope gradients and the impact of human disturbances. In addition to environmental factors influencing species diversity, anthropogenic disturbances significantly compromise it through habitat loss and fragmentation (Lyaruu *et al.,* 2000; Pimm and Raven, 2000; Brooks *et al.,* 2002). The intentional cutting or destruction of tree species likely contributes to the variations in species presence across different plots and slope classes. The greater suitability and accessibility of lower slope areas for humans and foraging animals may primarily account for the reduced species richness, diversity, evenness, and density of woody plant species observed in the low slope class (LSC).

The patterns of species density along slope gradients noted in this study indicate that the LSC has a lower density of woody species per hectare compared to the MSC and USC. This relationship among the slope classes

and woody species density is often linked to the productivity differences at the study area. For example, higher diversity has been associated with intermediate levels of productivity (Kassen *et al.,* 2000). The slightly elevated plant diversity recorded in the MSC and USC may result from reduced anthropogenic influences, which allow a greater number of species to coexist.

The woody species richness in the forests of the LSC was significantly lower than that in the MSC and USC (Table 4). Both the Shannon diversity indices and evenness values were noticeably lower in the LSC compared to the MSC and USC. Overall, species richness, diversity indices, evenness, and density were higher in the MSC and USC, with the USC exhibiting the highest values, followed by the MSC. Notably, the differences in mature woody species diversity between the MSC and USC were not statistically significant. Similarly, the average species richness value was higher at MSC and USC; mainly due to suitability of LSC for destruction by external forces (i.e. anthropogenic and fauna effects).

Regeneration Status of Woody Species

The average density of seedlings, saplings, and mature woody species in the Ades forest was found to be 117.9, 282.9, and 975.8 plants per hectare, respectively (Table 5). In comparison, the density for seedling, sapling, and mature woody plant species in the LSC were 106.3, 358.8, and 747.5 plants per hectare, which is notably lower than that of the MSC and USC. The MSC recorded a density of 120 seedlings, 286.3 saplings, and 928.8 mature woody species per hectare, which is higher than the LSC but still below the numbers of the USC. The USC exhibited the highest density, with 127.5 seedlings, 203.8 saplings, and a remarkable 1251.3 mature woody plants per hectare. Evaluating the regeneration status of plant communities is crucial for the sustainable conservation and management of any habitat (Khumbongmayum *et al.,* 2006).

Table 5: Regeneration status of woody species

	Slope class						Average density (ha^{-1})
	Lower		Middle		Upper		
	Density (ha^{-1})	%	Density (ha^{-1})	%	Density (ha^{-1})	%	
Seedling	106.3	8.8	120.0	9.0	127.5	8.1	117.9
Sapling	358.8	29.6	286.3	21.4	203.8	12.8	282.9
Matured	747.5	61.6	928.8	69.6	1251.3	79.1	975.8

The Lower Slope Class (LSC) exhibited a distribution of 61.6% mature trees, 29.6% saplings, and 8.8% seedlings. In comparison, the Midle Slope Class (MSC) comprised 69.6% mature individuals, 21.4% saplings, and 9% seedlings, while the Upper Slope Class (USC) demonstrated a greater proportion of 79.1% mature trees, 12.9% saplings, and 8.1% seedlings. The overall regeneration status across all examined woody species revealed a significantly lower percentage and density of seedlings and saplings per hectare, relative to mature trees. The combined percentages of saplings and seedlings in the LSC, MSC, and USC were found to be below that of mature woody plant individuals, indicating a concerning state of regeneration for the woody plant species within the study area. Conversely, the substantial presence of mature woody individuals across all slope classes underscores the age and maturity of the protected Ades forest.

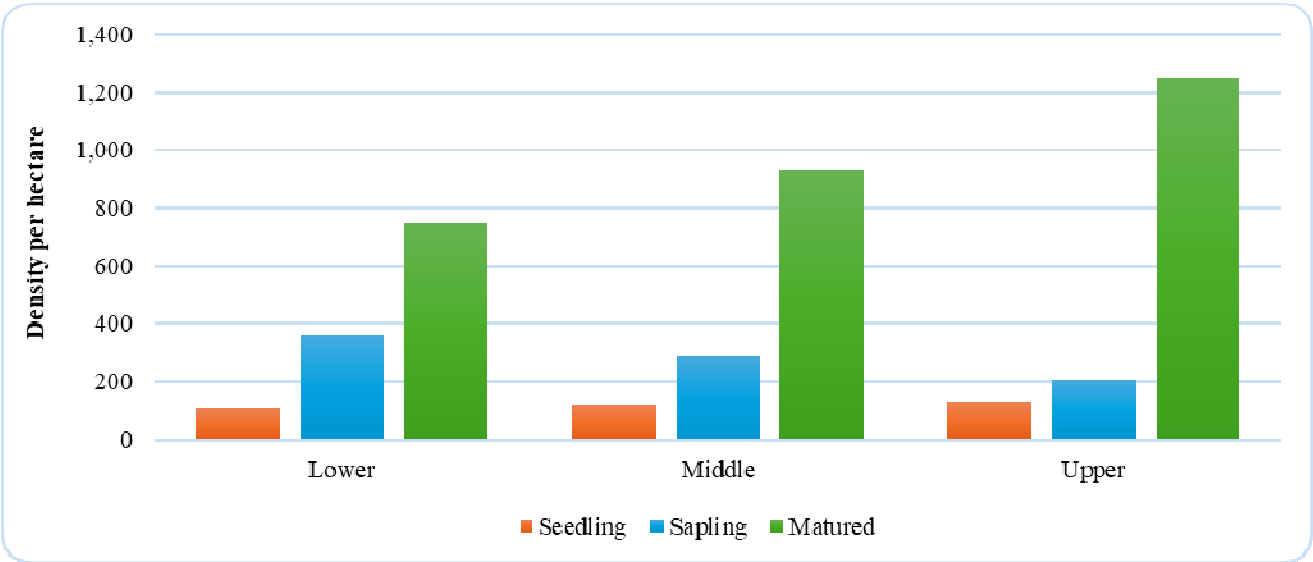

Figure 11: Regeneration status of Ades forest

When the number of seedlings of woody plants exceeds the number of saplings, and saplings outnumber mature trees and shrubs, it typically indicates a healthy state of vegetation regeneration (Khumbongmayum *et al.,* 2006). However, in the study area, the situation is quite different: mature woody plants outnumber saplings, and saplings are more abundant than seedlings. As a result, the combined total of saplings and seedlings is lower than the total number of mature individuals. This suggests that the study area is experiencing poor regeneration status and requires additional management efforts to improve the numbers of seedlings and saplings.

This study identified several anthropogenic factors that contribute to the decline of sapling and seedling populations within the study area. A significant concern is the harvesting of herbaceous forage via a cut-and-carry system, which removes seedlings during their early developmental stages. Furthermore, activities such as deforestation, illegal collection of firewood, charcoal production, and unregulated livestock grazing/browsing disrupt the growth of younger vegetation. Such practices can result in biodiversity loss, increased soil erosion, and depletion of fertile soils, particularly following deforestation on steep slopes (Birhanu, 2014).

Herbaceous Biomass Production and Basal Cover

Herbaceous Biomass production

Statistical analysis of biomass production ($P < 0.05$) indicates that the slope gradient significantly influences the biomass yield of herbaceous vegetation (see Table 6). Specifically, the lower slope class yields higher biomass production (1.22 tons ha^{-1}) compared to the middle slope class (1.09 tons ha^{-1}) and the upper slope class (1.03 tons ha^{-1}). This variation may be linked to differences in species richness, species diversity, soil nutrient availability, soil depth, and the amount of moisture existing in the soil across various slope gradients.

Table 6: Herbaceous vegetation basal cover and dry biomass yield

Parameters	Slope classes			±SE	*P*-value
	Lower	Middle	Upper		
DBMY(ton ha^{-1})	1.22^{a}	1.09^{b}	1.03^{c}	0.02	0.001
Basal Cover (%)	75.95^{a}	$66.55.0^{b}$	64.35^{b}	1.59	0.001

Where: ^{a,b,c} Means within a row with different superscripts differ significantly ($P < 0.05$).

Statistical analysis of herbaceous biomass production proves that slope gradient exerts a significant influence on biomass yield ($P < 0.05$). Notably, the lower slope class exhibits higher biomass production, yielding 1.22 tons per hectare, compared to the middle and upper slope classes, both of which yield 1.09 and 1.03 tons per hectare respectively. This discrepancy may be attributed to variations in species richness, species diversity, soil nutrient availability, soil depth, and the availability of soil moisture across different slope gradients.

Furthermore, variations in slope gradient have a substantial effect on the diversity and richness of herbaceous species. This finding suggests that slope gradient indirectly impacts biomass production. As articulated by Heidari *et al.,* (2010), the greatest species diversity and richness are observed in lower slope areas. Moreover, research conducted by Huang (2002) and Fang (2004) emphasises that slope gradient is a primary topographic factor influencing vegetation diversity and distribution patterns. A study by Mahdavi and Heidari (2009) elucidates that slope gradient percentage significantly affects species diversity. Additionally, Mirzaee (2006) notes that slope factors can either positively or negatively influence the presence of plant species. Thus, it can be concluded that slope gradient plays a crucial role in shaping the diversity and richness of herbaceous species, which in turn affects biomass production.

Soil nutrient availability is significantly influenced by slope gradient, with a greater concentration of available nutrients observed on lower slopes compared to upper slopes. Additionally, both the quantity and distribution of numerous nutrient elements are generally higher in flatter slope categories than in steeper slopes. Notably, elevated levels of available phosphorus (P), exchangeable potassium (K), and extractable micronutrients (including boron [B], copper [Cu], iron [Fe], and zinc [Zn]) have been documented in soils situated on flat slopes rather than on steep slope categories (Fanuel, 2015). Supporting findings from other research indicate that the distribution and quantity of most nutrient elements tend to be greater on flat slope categories compared to steeper slopes (Ali, 2010; Abrha, 2013; Desalegn, 2014). Furthermore, steeper slopes are more susceptible to soil erosion, which results in reduced soil depth and increased leaching of soil nutrients; thereby leading to lower concentrations of nutrient elements in these areas. A review focusing on the nature and causes of land degradation in the Oromia Region of Ethiopia has established that soils on steep slopes are typically shallower and exhibit limited nutrient and water storage capacities

(Bezuayehu et al., 2002). These findings indicate that the amount and distribution of soil nutrient elements crucially influence the herbaceous biomass production across various slope classes, resulting in decreased herbaceous biomass production in upper slope categories (USC) compared to mid-slope categories (MSC) and lower slope categories (LSC), respectively.

Moreover, herbaceous biomass production was substantially impacted by the availability of soil moisture, which is closely related to slope gradient. Numerous studies (Pachepsky *et al.,* 2001; Al-Seikh, 2006; Lovett *et al.,* 2006; Marshall *et al.,* 2012) have demonstrated that water availability and storage are significantly affected by the slope gradient. Consequently, the variations in soil moisture availability across different slope classes lead to pronounced differences in herbaceous biomass production, with USC exhibiting lower production than both MSC and LSC, respectively.

Herbaceous Basal Cover

The lower slope class (LSC) exhibits a higher percentage of basal cover in comparison to the middle slope class (MSC) and the upper slope class (USC) within the study area. This study demonstrates that the ground cover of herbaceous species in the LSC is significantly ($P < 0.05$) higher than that of the MSC and USC. The mean ground cover percentage for the LSC was 75.95, whereas the MSC and USC have mean basal cover percentages of 66.55 and 64.35, respectively (Table 6). Although there is a numerical difference between the MSC and USC, this difference is not deemed significant.

The observed variations in basal cover percentages may be ascribed to factors such as variations in soil nutrient availability, soil depth, and moisture content across different slope classes. The USC is characterized by a steeper gradient than both the MSC and LSC, rendering it more susceptible to soil erosion. The slope gradient represents a critical topographic factor influencing drainage, runoff, and soil erosion, subsequently affecting the physicochemical properties of the soil (Farmanullah, 2013). Steeper slopes are more vulnerable to erosion, leading to diminished soil depth and nutrient availability, which adversely affects the ground cover of herbaceous species.

Furthermore, shallower soils tend to possess lower water retention capacities, thus impacting the basal cover of herbaceous species on steeper gradients unfavorably. Previous studies have established that water availability serves as a principal environmental factor governing patterns of vegetation distribution (Zhao *et al.,* 2007). Consequently, the USC is notably more exposed to moisture loss, which in turn negatively influences the ground cover of herbaceous species in these steep terrains. Furthermore, reduced nutrient accessibility in the USC leads to diminished herbaceous coverage; it has been documented that levels of total nitrogen (TN), organic matter (OM), and cation exchange capacity (CEC) are typically higher in flatter slope regions in contrast to steeper slopes (Ali, 2010; Abrha, 2013; and Desalegn, 2014). Research conducted in northwestern Ethiopia also corroborates that mean values for TN, OM, and CEC are elevated in lower slopes compared to upper slopes, consequently resulting in lower basal cover of herbaceous species in steeper regions when compared to flatter areas (Gebreselassie *et al.,* 2015).

Conclusions and Recommendations

The analysis of floristic data across the three slope gradient classes in Ades forest indicates a medium level of species diversity compared to other forests in Ethiopia. The evaluation of woody vegetation shows that slope gradient class significantly influences woody species richness, diversity, evenness, density, dry biomass yield, and basal cover of herbaceous vegetation. Specifically, the lower slope class (LSC) exhibited lower mean values for woody species richness, diversity, evenness, and density compared to the middle slope class (MSC) and upper slope class (USC). However, the LSC had higher herbaceous dry biomass production than both the MSC and USC.

Moreover, the population structure of certain dominant species, selected for their high Importance Value Index (IVI), reveals that many of them have poor regeneration status, although the severity of this issue varies among species.

Among the tree species, Juniperus procera, Podocarpus falcatus, and Cupressus lucitanica are the dominant woody species with the highest densities recorded in Ades forest. The distribution of diameter at breast height (DBH) classes shows a decline in woody species as we progress from lower to higher DBH classes, along with a gradual increase in the number of large trees as the slope gradient increases. This decline in stem count indicates a normal and healthy population structure.

Overall, the findings suggest that slope gradient significantly influences the vegetation of Ades forest. However, other factors, such as anthropogenic impacts and increased fauna, are posing serious challenges to the forest's vegetation. Therefore, management strategies should consider the variations in slope gradient, and efforts should be made to mitigate anthropogenic effects through community awareness programs and participatory forest management approaches.

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